

# Product Quality and the Impact of Trade and Technology on the Relative Wage\*

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## ABSTRACT

Trade and technology have long been identified as two major factors responsible for the rising relative wage of skilled labor. This paper contributes to this literature by taking into consideration firms' endogenous choice of differentiated varieties produced with different skill requirements. Due to quality upgrading, the relative wage of skilled labor can increase in both a developed and a developing country after a tariff cut regardless of a country's relative factor endowment. This trade effect applies to both a small and a large open economy. On the other hand, the technology effect depends on a country's size and technology. Moreover, the relative skill intensity required to produce different varieties within a sector can play a more important role than the relative skill intensity between sectors.

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# 1 Introduction

Since Bhagwati and Ksters (1994) documented the first surge of research on the possible connections between global trade and rising wage inequality, there has been a continuous debate on what is the dominant force driving the wage inequality: trade or technology. The wage inequality has manifested as an increasing skill premium in wages paid in the US and as a higher unemployment rate for unskilled labor in Europe. Searching for the cause of this inequality has attracted much attention of both trade and labor economists, as summarized in Francois and Nelson (1998), Haskel (2000), Slaughter (1998), and Wood (1998). Deardorff (2000) proves that, if any policy remedy is needed to mitigate the wage inequality, the cause does not matter for the cure. Yet, analysis of the impact of trade and technology on factor prices provides better understanding of labor market evolution and more accurate prediction of future wage movements in an open economy.

The aim of this paper is to examine whether vertical product differentiation can change the impact of trade and technology on factor prices found in the existing literature. Rather than focusing on whether trade or technology dominates, the paper analyzes the additional factors that need to be considered to determine the relative wage impact of trade and technology when goods are vertically differentiated. Since many new products are higher quality versions of old goods, economic progress is typically associated with the appearance of new and superior varieties and the disappearance of old ones. New and higher quality goods bear higher prices as shown in Aw, Batra and Roberts (2001). Moreover, different qualities usually require different skill intensities to produce.<sup>1</sup> Thus, quality adjustment or the replacement of old varieties can provide an additional channel for trade and technology to affect factor prices, which is absent in the case with only homogeneous goods.

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<sup>1</sup>In this paper, a better or higher quality means a product with more characteristics and requires more skilled labor or more complicated procedure to produce as defined in Gabszewicz and Turrini (2000) and Kremer (1993). Empirically, Abowd, Kramarz, and Moreau (1995) find a weak, but generally positive, relation between worker skills and product quality using firm-level data from the French Producer Price index surveys.

In the literature, Leamer (1998 and 2000) and Krugman (2000) have provided two benchmark cases. Leamer shows empirically that trade is the main cause for a price-taking small open economy. This is because factor prices in a small open economy are determined by the world commodity prices and hence by the intersection of the two solid iso-cost curves in Figure 1, provided the country's endowment lies in the diversification cone. According to the Heckscher-Ohlin and Stolper-Samuelson theorems, trade liberalization shifts the iso-cost curve of a country's export good to the right (one of the dotted lines). This increases the relative demand and return to a country's relatively abundant factor that is used relatively more intensively in the country's export sector, as the country's import competing sector contracts and the export sector expands. Therefore, trade increases the relative wage of skilled labor in a developed country (relatively skilled labor abundant) and decreases that in a developing country (relatively unskilled labor abundant). On the other hand, skill biased technical progress in both sectors rotates the iso-cost curves and leaves equilibrium factor prices unchanged as shown in Figure 2.

For a large open economy, Krugman argues that the increase in production after trade liberalization will worsen the country's terms of trade and shift the iso-cost curve of its export good back to the left. If preferences are Cobb-Douglas, then trade has no effect on factor prices. Instead, the relative demand and supply of skilled labor is the key to determine the relative wage. Krugman argues that the relative wage of skilled labor increases regardless of which sector contracts or expands because the relative demand of skilled labor increases across all sectors as a result of skill biased technical progress. This is supported by the empirical work in Lawrence and Slaughter (1993), which document that there has been a rise in the college-educated share of employment since the 1970s, not only in the economy as a whole, but within almost every industry in US. Other empirical supports include Berman, Bound, and Machin (1994), Katz and Murphy (1992), Murphy and Welch (1992), and those summarized in Richardson (1995).

Since the shift and the rotation of the iso-cost curves depend on the elasticities of substitution, Xu (2001) reconciles the differences between Leamer and Krugman by analyzing the different impacts of technology on factor prices due to country size as well as consumption and production

elasticities. He concludes that Leamer's argument can be extended to any global but non-identical technical progress while the key condition for Krugman's argument to hold is that technical progress is global and identical across countries with Cobb-Douglas preferences.

In spite of this trade versus technology debate, the conventional trade argument predicts that trade liberalization always moves the relative wage in the developed and developing countries in the opposite directions while identical technical progress moves them in the same direction. This suggests that the recent findings of rising skill premium in some less developed or newly developed countries as well as in developed countries clearly favor technology over trade as the dominant force driving the rising wage inequality. Such findings are explored in Desjonquieres, Machin and Van Reenan (1999), Feenstra and Hanson (1997), and Hanson and Harrison (1999).

This paper shows that, as a result of quality upgrading, trade can increase a country's relative wage of skilled labor regardless of its relative endowment. Since different qualities are produced with different skill intensities, quality upgrading directly affects factor returns without having to operate through changes in relative product prices, which become endogenous with the choice of quality. This applies to both a large and a small open economy, and is consistent with the relatively stable product prices in the US despite the increase in the volume of trade found in Lawrence and Slaughter (1993). Thus, the simultaneous rise of skill premium in both developed and developing countries does not render the failure of trade as the major determinant of factor prices. The effect of technology depends on a country's size, in which sector technical progress occurs, and whether it is skill biased. In sum, the relative skill intensity required to produce different varieties within in a sector can play a more important role than the relative skill intensity between sectors. This is supported by the findings in Berman, Bound, and Machin (1994) that intraindustry (as opposed to interindustry) skill upgrading accounts for about 0.4 of the 0.55 share increase per year in US manufacturing.

To focus on the impact of product differentiation, the analysis in this paper takes specific utility and production functions to simplify any impact due to demand and supply elasticities well studied in the literature. Throughout the paper, we also confine our attention to the case where

neither country is perfectly specialized so that factor price equalization theorem holds under free trade and identical technology. This makes our results comparable to most of the existing literature on the Heckscher-Ohlin (H-O) trade model and allows us to observe the distinctive role of product differentiation. Under these assumptions, the following analysis is able to duplicate the relative wage effects of trade and technology observed in a conventional H-O model by holding quality fixed and to ensure that any deviation from the standard H-O results is due to the endogenous choice of quality.

There are a few other recent studies that have developed international trade models that link economic openness to changes in factor prices through the acceleration of endogenous technical change. Dinopoulos and Segerstrom (1999) link the relative factor prices to the expected discounted profits of conducting R&D, which plays a similar role as that of the relatively skill intensive sector in a standard H-O model. They endogenize workers' skill-acquisition process and demonstrate that lower tariffs increase wage inequality in both trading countries via skill upgrading rather than resource movement across industries. Dinopoulos, Syropoulos and Xu (1999) examine horizontal product differentiation in a Dixit-Stiglitz preference for diversity model and attribute the global rise in wage inequality to an increase in market size due to free trade. This paper incorporates the Lancaster characteristics model and identifies yet another trade-related mechanism: one that relates the endogenous choice of product quality to factor prices.

To model the monopolistic competition in the differentiated sector, this paper adopts the Helpman-Krugman general equilibrium approach.<sup>2</sup> Helpman (1981) and Helpman and Krugman (1985) analyze the pattern of trade and the welfare effects of trade in a monopolistic competition market with horizontal product differentiation. They focus on increasing returns to scale as the driving force of intraindustry trade rather than differences in quality and hence skill intensity in production. This paper relaxes their assumption of identical technologies and identical cost structures to emphasize the cost difference of producing different varieties.

Flam and Helpman (1987) also allow firms to have different cost structures so as to endogenize

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<sup>2</sup>A compendium of the trade models under monopolistic competition can be found in Grossman (1992).

a firm's choice of quality and to relate higher quality to more labor input in production. They use a Ricardian model with one factor of production to focus on the pattern of intraindustry trade dynamics as a result of population growth and technical progress.<sup>3</sup> Stokey (1991) extends the Flam-Helpman model to focus on international differences in labor quality and to analyze the impact of population size and human capital accumulation on the relative wage between developed and developing countries. This paper extends their quality model to include two factors in order to consider the relative wage effect. On the demand side, the paper follows the approach in Shaked and Sutton (1983 and 1984).

The remainder of the paper is organized as follows. Section 2 presents the model. Section 3 derives the equilibrium in an integrated economy. Section 4 discusses the effect of trade on the relative return to skill in the absence of any technical progress. Section 5 analyzes the impact of technical progress on the relative wage of skilled labor in a small and a large open economy. Section 6 concludes and discusses possible extensions.

## 2 The Model

The model includes two countries, home and foreign, and two goods,  $X$  and  $Y$ . Good  $X$  is vertically differentiated with quality  $q > 0$ . Good  $Y$  is homogeneous and is sold in a perfectly competitive market. There are two factors of production, skilled ( $S$ ) and unskilled ( $L$ ) labor. These two factors are perfectly mobile within each country but are immobile between countries.

Firms in the differentiated sector first choose a quality,  $q$ , and then a competitive price under free entry and exit. Each firm produces only one variety.<sup>4</sup> To isolate the impact of different skill

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<sup>3</sup>Copeland and Kotwal (1996) and Murphy and Shleifer (1997) also use a one factor model with different technologies and preferences to analyze the pattern of trade of vertically differentiated goods between developed and developing countries.

<sup>4</sup>If firms can produce more than one variety, then as long as the market is not a natural or protected monopoly studied in Mussa and Rosen (1978), results on market structure with single-product firms can be extended to

intensity requirements in producing different qualities, the following analysis assumes a perfectly inelastic differentiated sector for each given variety so that only a change in quality changes skill intensity. On the other hand, the homogeneous sector has a standard CES production technology.

The total output of good  $X$  with a given quality  $q$  is given by the following Leontief production function:

$$X(q) = \min\left\{\frac{L_x}{\mu_x}, \frac{S_x}{\lambda_x q^a}\right\}, \quad (1)$$

where  $L_x$  is the unskilled labor input and  $S_x$  is the skilled labor input in the  $X$ -sector. We assume that  $a > 0$ . Hence, for a given amount of unskilled and skilled labor, the total output is smaller for a good with a higher quality as in Flam and Helpman (1987), Copeland and Kotwal (1996), and Murphy and Shleifer (1997). The production in this differentiated sector is similar to that in the two factors and a continuum of goods model developed in Dornbusch, Fischer and Samuelson (1980) and Xu (1993), except that the range of skill intensity in this paper is not fixed, but is determined by quality that depends on consumers' preferences as well as cost of production. Also, there is an additional homogeneous sector to pick up the standard H-O effects.

Quality upgrading can affect the relative demand for skilled relative to unskilled labor in two ways. First, production of a higher quality good requires a higher fraction of skilled labor so that average variable cost increases in quality as studied in Acemoglu and Shimer (2000), Gabszewicz and Turrini (2000), and Kremer (1993). Second, the development (R&D) of a higher quality variety requires more skilled labor so that fixed cost increases in quality and can lead to natural oligopoly as emphasized in Shaked and Sutton (1983 and 1984).<sup>5</sup> The production function (1) has a zero fixed cost and focuses on the first case, or the ‘‘Chamberlinian’’ case labelled by Shaked and Sutton (1983), where quality upgrading mainly increases the average those with multiproduct firms as shown in Constantatos and Perrakis (1997) and Champsaur and Rochet (1989). A compendium of product differentiation models is provided by Beath and Katsoulacos (1991).

<sup>5</sup>In this case, the finiteness property holds so that there can only be a finite small number of firms coexist with positive market shares and price above average variable cost regardless of the size of the fixed cost. The conditions for the finiteness property to hold were first derived in Shaked and Sutton (1983) for firms with constant returns to scale and then expanded in Lahmandi-Ayed (2000) for firms with increasing or decreasing returns to scale.

variable cost. This assumption is consistent with the coexistence of numerous varieties in the market of manufacturing products as studied in Kraay, Soloaga and Tybout (2001).

The CES production function in the homogeneous sector is

$$Y = \left( \left( \frac{L_y}{\mu_y} \right)^\alpha + \left( \frac{S_y}{\lambda_y} \right)^\alpha \right)^{1/\alpha}, \quad \alpha \neq 1, \quad (2)$$

where  $Y$  is the total output of good  $Y$ ,  $L_y$  is the unskilled labor input and  $S_y$  is the skilled labor input in the  $Y$ -sector. Let  $\sigma = \frac{1}{1-\alpha}$  be the elasticity of substitution between skilled and unskilled labor. According to the result of most empirical studies, the following analysis only considers the case where  $\sigma > 1$ .<sup>6</sup>

The skill intensity of producing good  $X$  is

$$h_x = \frac{\lambda_x q^a}{\mu_x}. \quad (3)$$

Unlike in the case of homogeneous goods, the skill intensity in the  $X$ -sector depends on the endogenous choice of quality. Hence, there are two factors that can change the skill intensity in the  $X$ -sector: one is a **technical improvement** in producing all varieties in sector  $X$  indexed by  $\mu_x$  and  $\lambda_x$ , and the other is a firm's endogenous choice of **production technique** corresponding to its quality choice ( $q$ ) at the existing technology indexed by  $\mu_x$  and  $\lambda_x$ . The skill intensity in the  $Y$ -sector is

$$h_y = \left( \frac{\lambda_y}{\mu_y} \right)^{1-\sigma} \left( \frac{w_s}{w_l} \right)^{-\sigma}, \quad (4)$$

where  $w_l$  is the wage of unskilled labor and  $w_s$  is that of skilled labor.

Traditionally, there are two ways to classify factor (either skilled labor or unskilled labor) biased technical progress. One is by the factor-augmenting definition and the other is by the classification in Hicks (1932).<sup>7</sup> Since the focus of this paper is to study how quality differentiation

<sup>6</sup>The elasticity is 1.41 in Katz and Murphy (1992), 1.5 in Johnson (1997), and 1.67 in Krusell et al. (2000).

<sup>7</sup>Both of these classifications have been used in empirical studies of technical progress and relative wages. For example, Kahn and Lim (1998) estimate skill biased technical progress in US manufacturing based on the factor-augmenting classification, while Berman, Bound, and Machin (1998) provide international evidence on the implications of skill biased technical progress by the Hicksian classification. A detailed relationship between these two classifications are discussed in Jones (1965 and 2000), Neary (2001), and Xu (2001).

can change the effect of trade and technology on the relative wage, the following analysis takes the factor-augmenting classification unless stated otherwise to compare with the existing literature. This approach avoids the sector-factor debate as summarized in Feenstra and Hanson (1999), Leamer (1998 and 2000), Krugman (2000), and Xu (2001). Hence, a fall in  $\mu_x$  represents a unskilled labor biased/saving technical change in the  $X$ -sector and a fall in  $\mu_y$  represents that in the  $Y$ -sector, while a fall in  $\lambda_x$  represents a skilled labor biased/saving technical change in the  $X$ -sector and a fall in  $\lambda_y$  represents that in the  $Y$ -sector.

On the consumption side, each individual buys at most one unit of the differentiated good and her utility increases with quality.<sup>8</sup> After choosing her consumption of good  $X$ , the consumer spends her remaining income on the homogeneous good and her utility increases with the quantity of the homogeneous good consumed. The consumer's utility can be characterized by the following function:

$$U = \begin{cases} y + \theta \ln q & \text{if } q > 1 \\ y & \text{if } q \leq 1 \end{cases}, \quad (5)$$

where  $\theta$  indexes a consumer's marginal utility of quality with a higher  $\theta$  representing a consumer with a higher valuation on quality ( $q$ ).  $\theta$  is distributed over  $\underline{\theta}$  and  $\bar{\theta}$  with a density function  $f(\theta)$ .  $y$  is the consumption of good  $Y$ , and  $\ln q$  gives the utility from consuming a unit of good  $X$  with quality  $q > 1$ . A consumer can choose not to consume good  $X$  at all. This utility function is similar to that in Flam and Helpman (1987) and Mussa and Rosen (1978) except that a consumer's utility increases with quality but at a decreasing rather than increasing or constant rate. Also, in Flam and Helpman (1987), consumers choose different qualities due to their differences in incomes rather than preferences.<sup>9</sup>

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<sup>8</sup>This is a standard assumption in most studies on vertical product differentiation. This Lancaster (1979) quality ladder approach allows us to focus on the relationship between a better quality and its higher skill intensity in production. One can take the Dixit and Stiglitz (1977) expanding variety approach so that consumers can consume more than one variety. If producing more varieties requires a more skill intensive technique, then these two approaches would yield very similar results. Alternatively, we can extend the analysis by replacing  $q$  with  $xq$  in equation (5), where  $x$  is the quantity demanded at quality  $q$  as in Grossman and Helpman (1991), Motta (1992), and Sutton (1991).

<sup>9</sup>If we want to analyze the income effect on the choice of quality, we can take the alternative approach in Flam

To focus on the distinctive role of the endogenous choice of quality, the following analysis keeps the other standard assumptions in a H-O model whenever possible. As summarized in (A0), the home and foreign countries are assumed to be identical except for their endowments of skilled labor and unskilled labor,  $S$  and  $L$  for the home country, respectively, and  $S^*$  and  $L^*$  for the foreign country, respectively.<sup>10</sup> If each individual provides one unit of either skilled or unskilled labor, but not both, then the total population is  $L + S$  under full employment in the home country. It is also assumed that the home country is a developed country and the foreign country is a developing country so that the home country has a higher skilled-unskilled labor endowment ratio ( $S/L$ ). Finally, producers in the developed (home) country and the developing (foreign) country adopt the same technology and consumers have the same preference for the homogeneous good while their preference distribution over quality and price for the differentiated good is also the same.

**(A0)**  $S^*/L^* < S/L$ ,  $a^* = a$ ,  $\mu_x^* = \mu_x$ ,  $\lambda_x^* = \lambda_x$ ,  $f(\theta) = f^*(\theta)$ , and  $\underline{\theta}^* = \underline{\theta} < \bar{\theta} = \bar{\theta}^*$ .

### 3 Equilibrium in an Integrated Economy

Under free trade and identical technology, the relative wage in an integrated economy gives the equilibrium relative wage in all countries. Moreover, the equilibrium of the integrated economy with endowments  $L + L^*$  and  $S + S^*$  closely resembles that of a closed economy or a large open economy with the same endowments. This relationship in the presence of vertical production differentiation is investigated in the appendix.

To illustrate how a firm's endogenous choice of quality can change the impact of trade and 

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and Helpman (1987). The quasi-linear utility function in this paper makes the choice of quality independent of income as the homothetic utility function does for the H-O model. Most of the results in the paper will stay the same if  $\ln q$  is replaced by a more general utility function  $u(q)$  as long as  $u'' < 0$ . If  $u'' > 0$ , the market can become a natural oligopoly market as in Shaked and Sutton (1983). Also, the equilibrium can be unstable where the curve that gives the relative wage for a given quality from production intersects the curve where consumers choose their most desired quality at given factor prices.

<sup>10</sup>Hereafter, all the corresponding variables for the foreign country have an asterisk superscript.

technology on the relative wage of skilled labor, this section derives the equilibrium with endogenous quality in an integrated economy that serves as a benchmark for the analysis of the impact of trade liberalization and technical progress in the next two sections. For a comparison, the appendix derives the equilibrium in the case of a single fixed quality ( $q > 1$ ).

If firms can choose the qualities of their products in the differentiated sector, then firms have incentives to produce different qualities to gain some monopoly power. Under free entry and exit and zero fixed cost, each firm eventually earns zero profit and a continuous range of qualities is produced to satisfy each group of consumers with a particular  $\theta$ . For a given quality, each firm has the same average total cost derived from production function (1). Under monopolistic competition, price must equal the average variable cost of producing each variety  $q$ . Let  $p_q$  be the price of good  $X$  with quality  $q$  and  $p_y$  be the price of good  $Y$ . At given factor prices,

$$p_q = \mu_x w_l + \lambda_x q^\alpha w_s. \quad (6)$$

Under perfect competition in the homogeneous sector,  $p_y$  is equal to its marginal cost of production, which can be derived from the CES production function as follows (Varian, 1992, p.56).

$$p_y = ((\mu_y w_l)^{1-\sigma} + (\lambda_y w_s)^{1-\sigma})^{\frac{1}{1-\sigma}} = \mu_y w_l (1 + \frac{w_s}{w_l} h_y)^{\frac{1}{1-\sigma}} = 1. \quad (7)$$

We normalize the price of good  $Y$  to one, i.e.  $p_y = 1$ . Suppose  $I$  is a consumer's total income. If each consumer contributes one unit of labor, then a consumer's total income,  $I$ , is  $w_l$  for an unskilled labor or  $w_s$  for a skilled labor.<sup>11</sup> We first derive a consumer's choice of quality at given factor prices that determine the product prices at different qualities. Given her budget constraint and marginal utility of quality ( $\theta$ ), a consumer chooses her most preferred quality by solving the following maximization problem:

$$\max_q U = I - (\mu_x w_l + \lambda_x q^\alpha w_s) + \theta \ln q. \quad (8)$$

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<sup>11</sup>This income distribution assumption is not crucial as the utility function (5) is quasi-linear so that income does not change a consumer's relative preference across qualities.

At given factor prices, the first order condition shows that each consumer's optimal choice of quality is:

$$q(\theta) = \sqrt[a]{\frac{\theta}{a\lambda_x w_s}}. \quad (9)$$

From equation (7),

$$\frac{1}{w_s} = \frac{w_l}{w_s} \frac{1}{w_l} = \frac{w_l}{w_s} \mu_y \left(1 + \frac{w_s}{w_l} h_y\right)^{\frac{1}{1-\sigma}} = \mu_y \left(\left(\frac{w_s}{w_l}\right)^{\sigma-1} + \left(\frac{\lambda_y}{\mu_y}\right)^{\sigma-1}\right)^{\frac{1}{1-\sigma}} \quad (10)$$

Thus, a consumer with preference  $\theta$  chooses a variety with a higher quality if quality upgrading costs less, i.e.  $w_s/w_l$  is lower. As quality plays the role of quantity while the relative wage plays the role of relative prices that become endogenous in the differentiated sector, this negative relationship resembles a demand curve of higher quantity at lower prices and is represented by the *DD* curve in Figure 3. A higher  $\theta$  shifts the *DD* curve to the right as a consumer with a higher  $\theta$  is willing to buy a variety with a higher quality at any given price schedule determined by given factor prices.

Substituting (9) into (6), the equilibrium price schedule is:

$$p_q = p^*(\theta) = \mu_x w_l + \frac{\theta}{a}. \quad (11)$$

Since the endogenous choice of quality allows a firm to adjust its quality sold to a potential buyer, the price of the differentiated good depends on the buyer's preference but is independent of the skill augmenting factor ( $\lambda_x$ ) and the wage of skilled labor ( $w_s$ ). If  $\lambda_x$  or  $w_s$  falls, then it is less costly to produce a variety with a higher quality. Since the same quality can be produced at a lower cost, consumers are willing to switch to higher qualities so that firms produce higher quality goods while keep prices the same at equilibrium. As to be discussed later in more detail, quality upgrading can have a direct effect on the relative wage without operating through the change in product prices. This explains why the relative prices of skill-intensive goods have been quite stable despite the rapid technology improvement and trade liberalization over the past ten years (Desjonqueres et al., 2001; Lawrence and Slaughter, 1993).

On the consumption side, we finally assume that each consumer always buys one unit of good  $X$ . Since a consumer's utility is  $I$  if she spends all her money on good  $Y$ , she buys one unit of good  $X$  with quality given by equation (9) at a price given by equation (11) if and only if

$$I - p(\theta) + \theta \ln q(\theta) \geq I.$$

By substituting in equations (9) and (11), the above condition becomes  $\theta \geq \tilde{\theta}$ , where  $\tilde{\theta}$  satisfies  $\frac{\theta}{a}(\ln \frac{\theta}{a\lambda_x w_s} - 1) = \mu_x w_l$ . Hence, the above assumption requires that the existing technology in both countries is efficient to produce good  $X$  with the lowest quality to satisfy consumers with the lowest desire for quality. This full market coverage condition is imposed *ex post* throughout the paper so that technology is always efficient to cover the whole market. This is to assume that  $\underline{\theta}$  always lies to the right of  $\tilde{\theta}$  at factor prices, i.e. the following assumption holds both before and after a technical change with or without trade. This assumption also ensures that  $\theta \geq \underline{\theta} > a\lambda_x w_s^*$  so that  $q > 1$  at equilibrium.

**(A1)**  $a^* = a \geq 1$ ,  $\frac{\theta}{a}(\ln \frac{\theta}{a\lambda_x w_s} - 1) \geq \mu_x w_l$ , and  $\frac{\theta}{a}(\ln \frac{\theta}{a\lambda_x w_s^*} - 1) \geq \mu_x w_l^*$  at equilibrium.<sup>12</sup>

We now derive how a firm's choice of quality affects the relative wage. In a Walrasian equilibrium, the market for good  $Y$  must clear if all markets for different varieties of good  $X$  clear. Given the market clearing condition of each variety of good  $X$ ,  $\bar{X}(\theta) = X + X^* = f(\theta)(L + S + L^* + S^*)$ , the equilibrium relative wage of skilled to unskilled labor and the total production of good  $Y$  are determined by the following full employment conditions.

$$\int_{\underline{\theta}}^{\bar{\theta}} \mu_x f(\theta) d\theta + \mu_y (1 + \frac{w_s}{w_l} h_y)^{\frac{\sigma}{1-\sigma}} \bar{y} = l \quad (12)$$

$$\int_{\underline{\theta}}^{\bar{\theta}} \lambda_x q^a f(\theta) d\theta + h_y \mu_y (1 + \frac{w_s}{w_l} h_y)^{\frac{\sigma}{1-\sigma}} \bar{y} = s \quad (13)$$

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<sup>12</sup>The second order condition for (8) is  $\frac{d^2 U}{dq^2} = -a(a-1)\lambda_x w_s q^{a-2} - \frac{\theta}{q^2}$ , which is negative if  $a \geq 1$ . The intuition of this assumption is that, if  $a$  is large, then quality improvement requires a large increase in marginal cost to fence off consumption so that different consumers have different preferences on quality if charged at average variable cost. Thus, the finiteness property in Shaked and Sutton (1983) does not hold so that there is an infinite number of firms with zero profits as in the Shaked and Sutton "Chamberlinian" case. Similar results are shown in Mussa and Rosen (1978, section 2), Shaked and Sutton (1983), and a series of related papers collected in Thisse and Norman (1994).

where  $l = \frac{L+L^*}{L+S+L^*+S^*}$ ,  $s = \frac{S+S^*}{L+S+L^*+S^*}$ , and  $\bar{y} = \frac{Y+Y^*}{L+S+L^*+S^*}$ .

By substituting the definition of  $h_y$  (4) and (12) into (13), it is easy to see that quality and the relative wage  $w_s/w_l$  are positively related as quality upgrading pushes up the relative demand for skilled labor. This resembles the supply curve and is represented by the  $SS$  curve in Figure 3. For each firm targeting the group of consumers with  $\theta$  taking the others production as given, we can rewrite (13) as

$$\lambda_x q^a f(\theta) + h_y(l - \mu_x) = s - \int_{\phi \in [\underline{\theta}, \bar{\theta}] \text{ and } \phi \neq \theta} \lambda_x q^a f(\phi) d\phi.$$

$\int_{\phi \in [\underline{\theta}, \bar{\theta}] \text{ and } \phi \neq \theta} \lambda_x q^a f(\phi) d\phi$  decreases with  $\theta$  as consumers with higher  $\theta$ 's consume higher qualities. Hence, the  $SS$  curve shifts to the right for a higher  $\theta$ , i.e. firms supply consumers with higher  $\theta$ 's higher qualities at any given relative wages as these consumers are willing to pay more.

The equilibrium relative wage and quality is given by the intersection of the  $DD$  and  $SS$  curves in Figure 3, where the equilibrium relative wage is unique and the equilibrium quality increases with  $\theta$ . To formally solve for the equilibrium, rearranging (12) gives

$$\bar{y} = \frac{l - \mu_x}{\mu_y} \left(1 + \frac{w_s}{w_l} h_y\right)^{\frac{\sigma}{\sigma-1}}. \quad (14)$$

Substituting (14) and (10) into (13) gives the following equation to solve for  $w_s/w_l$ .

$$\begin{aligned} s &= \frac{\mu_y E[\theta]}{a} \frac{w_l}{w_s} \left(1 + \frac{w_s}{w_l} h_y\right)^{\frac{1}{1-\sigma}} + h_y(l - \mu_x) \\ &= \frac{\mu_y E[\theta]}{a} \left(\left(\frac{w_s}{w_l}\right)^{\sigma-1} + \left(\frac{\mu_y}{\lambda_y}\right)^{\sigma-1}\right)^{\frac{1}{1-\sigma}} + h_y(l - \mu_x), \end{aligned} \quad (15)$$

where  $E[\theta] = \int_{\underline{\theta}}^{\bar{\theta}} \theta f(\theta) d\theta$ .

From equation (14), if  $\mu_x \geq l$ , then technology is not efficient enough to produce both goods so that  $\bar{y} = 0$  regardless of whether quality is endogenously chosen. The following analysis assumes (A2) so that good  $Y$  is produced in both countries. Each consumer with  $\theta$  in either country consumes one unit of good  $X$  with quality  $q(\theta)$  determined by (9) at price  $p_q$  determined by (11) and  $y$  units of good  $Y$  given by her budget constraint at unit price. The total production and consumption of good  $Y$ ,  $\bar{y}(L+S+L^*+S^*)$ , is given by equation (14). The factor prices are given by equations (10) and (15).

**(A2)**  $\mu_x < \min\left(l, \frac{L}{L+S}, \frac{L^*}{L^*+S^*}\right)$ .

## 4 The Impact of Trade Liberalization

To make the following analysis comparable to the existing literature on the H-O model, it is assumed that firms in both countries produce all varieties of good  $X$  and good  $Y$  so that Factor Price Equalization (FPE) holds under free trade and identical technology.<sup>13</sup> Otherwise, trade can change the varieties that a country specializes in and cause an additional terms of trade effect even in a small open economy. Making this comparable assumption (requiring (A0) to (A2)) allows us to derive similar H-O results by holding quality exogenous so as to highlight the distinctive impact of endogenous choice of quality.

All equilibrium conditions are summarized in Table 1 if quality is exogenous and Table 2 if quality is endogenous. It is easy to observe that the endogenous choice of quality plays a limited role in deviating from the standard terms of trade effect of a large economy as those discussed exclusively in Krugman (2000) and Xu (2001). Hence, the following comparison between the case of endogenous quality and that of exogenous quality considers the case of a small open economy only.

For a small open economy, the prices are given by the world commodity prices and are independent of endowments even when quality is endogenously chosen as long as the country's endowments fall in the diversification zone or the imperfect specialization parallelogram. The factor prices are determined by (7) and

$$\mu_x w_l + \frac{\theta}{a} = p_q^* = p^*(\theta), \text{ for each given } \theta. \quad (16)$$

Since  $p_q^* = p^*(\theta)$  is given by equation (11) at factor prices derived from equations (10) and (15) in an integrated economy, equation (16) holds for all  $\theta$  if holds for one  $\theta$ .

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<sup>13</sup>The results of vertical product differentiation in the non-diversification zone where FPE fails even under free trade and identical technology are also very interesting. As illustrated in Flam and Helpman (1987), Copeland and Kotwal (1996), and Murphy and Shleifer (1997), product differentiation can break down trade between countries with very different income and technology if labor is the only input. This can also happen when there are two factors and identical technology, but this issue on pattern of trade is beyond the scope of this paper and will be addressed separately.

With exogenous quality, the relative wage in a small open economy is implicitly determined by the following equation:

$$\mu_x + \lambda_x q^a \frac{w_s}{w_l} = p_q^* \mu_y \left(1 + \left(\frac{w_s}{w_l}\right)^{1-\sigma} \left(\frac{\lambda_y}{\mu_y}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}, \quad (17)$$

which is derived by dividing both sides of equations (6) and (7) by  $w_l$  and then substituting (4) and the new (7) into the new (6). Similarly, by replacing equation (6) with (16) in the above derivation, the relative wage is implicitly determined by the following equation if quality is endogenous:

$$\left(p_q^* - \frac{\theta}{a}\right) \left(1 + \left(\frac{w_s}{w_l}\right)^{1-\sigma} \left(\frac{\lambda_y}{\mu_y}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}} = \frac{\mu_x}{\mu_y}. \quad (18)$$

To incorporate a tariff into the above equilibrium condition in a small open economy, we replace  $p_q^*$  with  $p_q = p_q^*(1+t)$  in equations (17) and (18) if a given variety of good  $X$  is imported. If the country imports good  $Y$  instead, then we replace  $p_q = p_q^*$  with  $\frac{p_q^*}{1+t}$  to keep good  $Y$  as the numeraire. The tariff rate,  $t$ , takes value between 0 and 1. Hence, a tariff cut reduces the price of good  $X$  with a given quality if it is imported and increases its price if good  $Y$  is imported.

Totally differentiating equation (17) gives

$$\frac{d\left(\frac{w_s}{w_l}\right)}{dp_q} = \frac{\mu_y \left(1 + \left(\frac{w_s}{w_l}\right)^{1-\sigma} \left(\frac{\lambda_y}{\mu_y}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}}{\lambda_x q^a - p_q \lambda_y \left(1 + \left(\frac{w_s}{w_l} \frac{\lambda_y}{\mu_y}\right)^{\sigma-1}\right)^{\frac{\sigma}{1-\sigma}}}.$$

Applying the Chain Rule and using equations (3) and (4) to rewrite the derivative in terms of skill intensities of production,  $h_x$  and  $h_y$ , give

$$\frac{d\left(\frac{w_s}{w_l}\right)}{dt} = \begin{cases} A & \text{if good } X \text{ is imported} \\ -\frac{A}{(1+t)^2} & \text{if good } Y \text{ is imported} \end{cases},$$

$$A = \frac{p_q^* \mu_y \left(1 + h_y \frac{w_s}{w_l}\right)^{\frac{1}{1-\sigma}}}{h_x - \frac{\lambda_y}{\mu_x} p_q \left(1 + \frac{1}{h_y \frac{w_s}{w_l}}\right)^{-\frac{\sigma}{\sigma-1}}}.$$

The above condition shows that if quality is exogenous, the Stolper-Samuelson theorem still holds in spirit although the condition determining the relationship between factor prices and

commodity prices is modified in this case where a consumer's utility depends on the quality of good  $X$  instead of quantity as in a standard H-O model. Namely, if the given quality of good  $X$  is high so that  $h_x \geq \frac{\lambda_y}{\mu_x} p_q^* (1 + \frac{1}{h_y \frac{w_s}{w_l}})^{-\frac{\sigma}{\sigma-1}}$  and  $A \geq 0$ , i.e. the skill intensity in the  $X$  sector ( $h_x$ ) is relatively high compared with that in the  $Y$  sector ( $h_y$ ), then a tariff cut reduces the relative wage of skilled labor in a country importing good  $X$ , and increases the relative wage in a country importing good  $Y$ . The reverse is true if the given quality of good  $X$  is low so that  $h_x < \frac{\lambda_y}{\mu_x} p_q^* (1 + \frac{1}{h_y \frac{w_s}{w_l}})^{-\frac{\sigma}{\sigma-1}}$  and  $A < 0$ .

In both cases at any given quality, the relative wage of skilled labor falls after trade liberalization in a developing country importing the relatively skilled labor intensive good and increases in a developed country importing the relatively unskilled labor intensive good. This is because a tariff cut reduces the relative price of a country's import, which uses relatively more intensively a country's relatively scarce factor by the Heckscher-Ohlin theorem. The Stolper-Samuelson theorem then predicts that the relative wage of a country's relatively scarce factor falls as the import competing sector contracts due to lower profitability after a tariff cut.

We now analyze the impact of a tariff cut on the relative wage when quality is endogenous. For simplicity, the following analysis assumes that a uniform tariff is imposed on all varieties of good  $X$  so that a tariff cut does not change the relative price between varieties. Equation (18) clearly shows that the relationship between factor prices and commodity prices are independent of the relative skill intensity between sectors if quality is endogenous. Since the pattern of trade is indeterminate when quality is endogenous, there can be intraindustry trade in the differentiated sector and a country can either import or export good  $Y$  in a trade equilibrium. The following derivative of equation (18) shows that a tariff cut increases the relative wage of skilled labor in any country that imports at least one variety of the differentiated good.

$$\frac{d(\frac{w_s}{w_l})}{dt} = \begin{cases} -B < 0 & \text{if good } X \text{ is imported} \\ \frac{B}{(1+t)^2} > 0 & \text{if good } Y \text{ is imported} \end{cases},$$

$$B = \frac{1 + h_y \frac{w_s}{w_l}}{(p_q - \frac{\theta}{a}) h_y} = \frac{1 + h_y \frac{w_s}{w_l}}{\mu_x w_l h_y} > 0.$$

Thus, both the developing and the developed countries can experience a rising relative wage of skilled labor after trade liberalization as long as some varieties of good  $X$  is imported and these varieties of good  $X$  can be either relatively more or less skilled labor intensive than the other varieties exported or good  $Y$  if exported. Since firms want to produce different varieties under monopolistic competition, firms in each country are likely to produce all varieties that are profitable. However, a country's endowment has to exactly match its preferences so that a country produces all it consumes at full employment. Otherwise, intraindustry trade exists. This result provides one explanation that trade liberalization can lead to rising wage inequality in both the developed and developing countries regardless of a country's relative endowment due to endogenous quality upgrading. Hence, the empirical result of simultaneous increase of skill premium does not rule out trade as an important determinant of the relative wage.

The reason is that a tariff cut shifts the  $DD$  curve to the right and the  $SS$  curve to the left, both pushes up the relative wage. (To be explained further.) If at least one variety of good  $X$  (not the one with the lowest quality) is imported, then a tariff cut increases the relative demand of a variety with a higher quality ( $q_h$ ) and decreases that of the variety with the lowest quality ( $\underline{q}$ ) even if the price of a higher quality ( $p_h$ ) as well as that of the lowest quality ( $\underline{p}$ ) both decrease by the same proportion as  $t$  falls if they are both imported. This is because the following conditions for a higher quality variety to be preferred to the lowest quality variety is more likely to be satisfied as  $t$  becomes smaller.

$$\begin{cases} \theta(\ln q_h - \ln \underline{q}) > (p_h - \underline{p})(1 + t) & \text{if the lowest variety is imported} \\ \theta(\ln q_h - \ln \underline{q}) > p_h(1 + t) - \underline{p} & \text{if the lowest variety is not imported} \end{cases}$$

This change in relative demand applies to any two varieties with different qualities. The increasing relative demand leads to more production of varieties with higher qualities in both countries. This quality upgrading dominates the effect of potential decrease in domestic production of the differentiated good due to a tariff cut and increases the relative demand and thus the relative wage of skilled labor regardless of the initial relative skill intensity between sectors.

**Proposition 1.** *The Stolper-Samuelson theorem holds if quality is exogenous. Trade liberalization increases the relative wage of skilled labor in a developed country (relatively skilled*

*labor abundant), and decreases the relative wage of skilled labor in a developing country (relatively unskilled labor abundant). However, if quality is endogenous and if FPE holds under free trade, trade liberalization increases the relative wage of skilled labor in any country that imports at least one variety of the differentiated good (if not the one with the lowest quality), regardless of a country's relative endowment. Thus, the relative wage can rise in both a developed and a developing country after a tariff cut.*

## 5 The Impact of Technology Progress

Proposition 1 shows that the equilibrium of the integrated economy with endowments  $L + L^*$  and  $S + S^*$  closely resembles that in a closed economy. As the endowments are assumed to be in the imperfect specialization parallelogram, the relative wage in each country is the same as the one in an integrated equilibrium. Therefore, the impact of technical progress on the relative wage in a large open economy is the same as that in a closed economy with endowments  $L + L^*$  and  $S + S^*$ . This section proceeds to compare the impact of technical progress as an exogenous reduction in the  $\mu$ 's and/or  $\lambda$ 's in a case where quality is exogenous to a case where quality is endogenous.<sup>14</sup> The comparison is first carried out in a small open economy and then in a closed economy. The results in the latter comparison apply to a large open economy as well.

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<sup>14</sup>Chuang (1998), Falvey and Reed (2000), and Wood (1994) consider the possibility of trade-induced technical progress in both the developed and developing countries. Acemoglu and Zilibotti (2001) and Grossman and Helpman (1991) analyze explicitly the endogenous dynamic process of innovation and imitation in an open economy. But, the issue of trade-related technical progress is beyond the scope of this paper.

## 5.1 In a small open economy

In a small open economy with exogenous quality, we consider a local technical change as in Leamer (1998 and 2000) for comparison. Totally differentiating equation (17) gives

$$\begin{aligned}\frac{d(\frac{w_s}{w_l})}{d\lambda_x} &= -\frac{q^a \frac{w_s}{w_l}}{\Delta_{t-ex}}, \\ \frac{d(\frac{w_s}{w_l})}{d\mu_x} &= -\frac{1}{\Delta_{t-ex}},\end{aligned}$$

for the differentiated sector and

$$\begin{aligned}\frac{d(\frac{w_s}{w_l})}{d\lambda_y} &= \frac{p_q^*}{\Delta_{t-ex}} \left(1 + \frac{w_s}{w_l} h_y\right)^{\frac{\sigma}{1-\sigma}} \left(\frac{w_s}{w_l}\right)^{1-\sigma} \left(\frac{\lambda_y}{\mu_y}\right)^{-\sigma}, \\ \frac{d(\frac{w_s}{w_l})}{d\mu_y} &= \frac{p_q^*}{\Delta_{t-ex}} \left(1 + \frac{w_s}{w_l} h_y\right)^{\frac{\sigma}{1-\sigma}},\end{aligned}$$

for the homogeneous sector, where  $\Delta_{t-ex} = h_x - \frac{\lambda_y}{\mu_x} p_q \left(1 + \frac{1}{h_y \frac{w_s}{w_l}}\right)^{-\frac{\sigma}{\sigma-1}}$ .

Under the modified condition of the relative skill intensity between sectors, if  $\Delta_{t-ex} \geq 0$ , i.e. the differentiated sector is relatively more skilled labor intensive than the homogeneous sector, then any technical progress in sector  $X$  (either a fall in  $\lambda_x$  or  $\mu_x$ ) increases the relative wage of skilled labor and any technical progress in sector  $Y$  (either a fall in  $\lambda_y$  or  $\mu_y$ ) decreases the relative wage of skilled labor. The opposites are true if  $\Delta_{t-ex} < 0$ .

Therefore, the standard result in a small open economy holds if quality is exogenous. Namely, the relative wage of skilled labor increases if technical progress occurs in the relatively skilled labor intensive sector and decreases if technical progress occurs in the relatively unskilled labor intensive sector. This is because technical progress within a small open economy reduces the marginal cost of production while leaving the commodity prices unchanged so that the sector where technical progress occurs expands.

In a small open economy with endogenous quality, multiplying equation (18) by  $\mu_y$  and then taking the total derivatives gives

$$\frac{d(\frac{w_s}{w_l})}{d\lambda_x} = 0,$$

$$\frac{d(\frac{w_s}{w_l})}{d\mu_x} = \frac{1}{\mu_y h_y (p_q^* - \frac{\theta}{a})} (1 + \frac{w_s}{w_l} h_y)^{\frac{\sigma}{\sigma-1}} > 0,$$

for the differentiated sector and

$$\begin{aligned} \frac{d(\frac{w_s}{w_l})}{d\lambda_y} &= -\frac{1}{\lambda_y} \frac{w_s}{w_l} < 0, \\ \frac{d(\frac{w_s}{w_l})}{d\mu_y} &= -\frac{1}{\lambda_y} \left(\frac{w_s}{w_l} \frac{\lambda_y}{\mu_y}\right)^\sigma < 0, \end{aligned}$$

for the homogeneous sector.

Therefore, if quality becomes endogenous in a small open economy, then the impact of technical progress on the relative wage no longer depends on the relative skill intensity between sectors. Instead, if technical progress occurs in the homogeneous sector (a fall in either  $\lambda_y$  or  $\mu_y$ ), the relative return to skilled labor increases. If technical progress occurs in the differentiated sector, the relative wage decreases if it is unskilled labor augmenting (a fall in  $\mu_x$ ) and stays the same if it is skilled labor augmenting (a fall in  $\lambda_x$ ).

The intuition is that, at given world prices, a technical improvement in the homogeneous sector causes labor moving from the differentiated sector to the homogeneous sector as the profitability in the homogeneous sector increases. If the homogeneous sector competes for skilled labor, then the relative wage of skilled labor increases. If the homogeneous sector competes for unskilled labor, then the relative wage of skilled labor also increases because of the quality upgrading when there is less unskilled labor in the differentiated sector. On the other hand, a technical improvement in the differentiated sector not only changes the relative cost of producing good  $X$  and good  $Y$ , but also that of producing different varieties of good  $X$ . If technical progress is skilled labor saving, then quality upgrading exactly uses up all the skilled labor saved by the new technology and leaves the relative demand and hence wage unchanged. If technical progress is unskilled labor saving, then it is profitable for firms to lower qualities to take advantage of the more efficient unskilled labor. As a result, the relative wage of skilled labor falls. This is true for skilled labor saving technical progress as well if quality upgrading does not absorb all surplus skilled labor.

**Proposition 2.** *In a small open economy, the impact of technical progress on the relative wage of skilled labor can be determined by sector regardless of whether quality is endogenous. However, if quality is exogenous, the criterion is whether technical progress occurs in a relatively skilled labor intensive sector: the relative wage increases if so and decreases if otherwise. If quality is endogenous, the criterion changes to whether technical progress occurs in a differentiated sector that decreases the relative wage of skilled labor or in a homogeneous sector that increases the relative wage.*

## 5.2 In a large open economy

In a large open economy with exogenous quality, we consider a global and identical technical change as in Krugman (2000) for comparison. Totally differentiating equation (A.5) with respect to the relative wage and technology parameters gives the impact of technology on skill premium,  $w_s/w_l$ . Let  $\Delta_{a-ex} = \sigma(\frac{w_s}{w_l})^{\sigma-1} > 0$ . In the differentiated sector,

$$\begin{aligned}\frac{d(\frac{w_s}{w_l})}{d\lambda_x} &= \frac{1}{\Delta_{a-en}} \frac{d}{d\lambda_x} \left( \frac{l - \mu_x}{s - \lambda_x q^a} \left( \frac{\mu_y}{\lambda_y} \right)^{\sigma-1} \right) = \frac{q^a}{\Delta_{a-en}} \frac{l - \mu_x}{(s - \lambda_x q^a)^2} \left( \frac{\mu_y}{\lambda_y} \right)^{\sigma-1} > 0, \\ \frac{d(\frac{w_s}{w_l})}{d\mu_x} &= -\frac{1}{\Delta_{a-en}} \frac{1}{s - \lambda_x q^a} \left( \frac{\mu_y}{\lambda_y} \right)^{\sigma-1} < 0.\end{aligned}$$

In the homogeneous sector,

$$\begin{aligned}\frac{d(\frac{w_s}{w_l})}{d\lambda_y} &= -\frac{\sigma - 1}{\lambda_y \Delta_{a-en}} \frac{l - \mu_x}{s - \lambda_x q^a} \left( \frac{\mu_y}{\lambda_y} \right)^{\sigma-1} < 0, \\ \frac{d(\frac{w_s}{w_l})}{d\mu_y} &= \frac{\sigma - 1}{\lambda_y \Delta_{a-en}} \frac{l - \mu_x}{s - \lambda_x q^a} \left( \frac{\mu_y}{\lambda_y} \right)^{\sigma-2} > 0.\end{aligned}$$

Thus, in terms of Hicksian classification, factor bias determines the impact of technical progress as derived in Krugman (2000) and Xu (2001) if quality is exogenous. Namely, a Hicksian skilled labor biased technical progress, either a fall in  $\mu_x$  that increases  $h_x$  or a fall in  $\lambda_y$  that increases  $h_y$ , increases the relative wage of skilled labor; while a Hicksian unskilled labor biased technical progress, either a fall in  $\lambda_x$  that decreases  $h_x$  or a fall in  $\mu_y$  that decreases  $h_y$ ,

decreases the relative wage of skilled labor. This is because a factor biased technical change by the Hicksian classification is equivalent to a decrease of the relative endowment of that factor, which increases the relative return to that factor in a closed economy.

If quality is endogenous, the impact of technology on skill premium,  $w_s/w_l$ , is given by totally differentiating equation (15) with respect to the relative wage and technology parameters. In the differentiated sector,

$$\begin{aligned}\frac{d(\frac{w_s}{w_l})}{d\lambda_x} &= 0, \\ \frac{d(\frac{w_s}{w_l})}{d\mu_x} &= -\frac{h_y}{\Delta_{a-en}} < 0,\end{aligned}$$

where  $\Delta_{a-en} = \frac{\mu_y E[\theta]}{a} ((\frac{w_s}{w_l})^{\sigma-1} + (\frac{\mu_y}{\lambda_y})^{\sigma-1})^{\frac{\sigma}{1-\sigma}} (\frac{w_s}{w_l})^{\sigma-2} + \sigma h_y (\frac{w_s}{w_l})^{-1} (l - \mu_x) > 0$ . In the homogeneous sector,

$$\begin{aligned}\frac{d(\frac{w_s}{w_l})}{d\lambda_y} &= \frac{1}{\Delta_{a-en}} \frac{\mu_y}{\lambda_y} h_y \left(1 + \frac{w_s}{w_l} h_y\right)^{\frac{\sigma}{1-\sigma}} \left(\frac{E[\theta]}{a} - (\sigma - 1)y\right) \begin{cases} \geq 0 & (1) \text{ if } \frac{E[\theta]}{a} \geq (\sigma - 1)y \\ < 0 & (2) \text{ if } \frac{E[\theta]}{a} < (\sigma - 1)y \end{cases}, \\ \frac{d(\frac{w_s}{w_l})}{d\mu_y} &= \frac{1}{\Delta_{a-en}} \left(1 + \frac{w_s}{w_l} h_y\right)^{\frac{\sigma}{1-\sigma}} \left(\frac{E[\theta]}{a} \left(\frac{w_s}{w_l}\right)^{-1} + (\sigma - 1)h_y y\right) > 0.\end{aligned}$$

Compared with the case of exogenous quality, the effect of unskilled labor saving technical progress in both sectors (a fall in  $\mu_x$  or  $\mu_y$ ) stays the same while only the effect of skilled labor saving technical progress changes due to the endogenous choice of quality.

In the differentiated sector, the equilibrium skill intensity is derived by substituting the endogenous choice of quality given by equation (9) into (3), which yields

$$h_x = \frac{\theta}{a\mu_x} \frac{1}{w_s}. \quad (4')$$

Thus, a fall of  $\lambda_x$  is Hicksian neutral and has no effect on the relative wage, while a fall of  $\mu_x$  still represents a Hicksian skilled labor biased technical change that increases the relative wage of skilled labor.

In the homogeneous sector, the impact of a fall of  $\lambda_x$  becomes ambiguous if quality is endogenous. From equation (11),  $\theta/a$  gives the total cost of skilled labor used to produce one

unit of good  $X$  for a consumer with preference  $\theta$  so that  $E[\theta]/a$  gives the total cost of skilled labor used in producing good  $X$  on average. Since  $p_y = 1$ ,  $y$  gives the per capita expenditure on good  $Y$ . Thus, if the  $X$ -sector, on average, uses a lot of skilled labor and the elasticity of factor substitution in the  $Y$ -sector is only slightly above one so that the total payment to skilled labor to produce one unit of good  $X$  ( $E[\theta]/a$ ) is, on average, greater than  $\sigma - 1$  times the per capita spending on good  $Y$  ( $y$ ), then a skilled labor saving technical change (a fall in  $\lambda_x$ ) in sector  $Y$  decreases the relative demand for skilled labor and hence its relative wage. Otherwise, skill premium increases.

The intuition is that, after a skilled labor saving technical change occurred in sector  $Y$ , the less elastic is the substitution between skilled and unskilled labor, the less is the output in sector  $Y$ , and the higher is the skill requirement for quality upgrading in sector  $X$ , the more likely is it for skilled labor to stay in sector  $Y$ . As a result, an induced quality upgrading in sector  $X$  is less likely to occur, and hence a skilled labor saving technical change in sector  $Y$  is more likely to create a relative surplus of skilled labor. Thus, the relative wage of skilled labor falls as  $\lambda_y$  falls if  $E[\theta]/a > (\sigma - 1)y$ .

**Proposition 3.** *In a closed economy or a large open economy, the impact of technical progress on the relative wage of skilled labor is determined by factor only if quality is exogenous while both factor and sector matter if quality is endogenous. If quality is exogenous, the relative wage of skilled labor increases after a Hicksian skilled labor biased technical change and decreases after a Hicksian unskilled labor biased technical change. The endogenous choice of quality only changes the impact of skilled labor saving technical progress. One in the differentiated sector becomes Hicksian neutral and has no effect on the relative wage. One in the homogeneous sector increases the relative wage of skilled labor if  $E[\theta]/a \leq (\sigma - 1)y$  and decreases the relative wage if otherwise.*

## 6 Conclusions and Extensions

This paper analyzes the effect of trade and technology on the relative wage when a firm can endogenously choose product quality and when varieties with different qualities require different skill intensities to produce. In addition to the demand and supply substitution effects studied in the existing literature, product differentiation creates an additional channel for trade liberalization and technical progress to affect factor prices: through quality upgrading instead of production expansion in the differentiated sector.

Since the analysis focuses on specific forms of utility and production functions, the results are comparable to most of the existing literature on the Heckscher-Ohlin trade model. Therefore, the analysis highlights the distinctive role of the endogenous choice of quality in the trade-technology debate when there is intraindustry trade of differentiated goods as well as inter-industry trade of homogeneous goods. With vertical product differentiation, the relative wage of skilled labor can increase in both a developed and a developing country after trade liberalization regardless of a country's relative factor endowment. This trade effect due to quality upgrading applies to both a small and a large open economy. In a large open economy, there is an additional terms of trade effect, just as in the case where quality is exogenous.

The impact of technology on factor prices depends on a country's size and openness, but the impact of technology in a large open economy resembles those in a closed/integrated economy regardless of the endogenous choice of quality. The technology impact depends on not only which sector technical progress occurs but also whether it is skilled or unskilled labor saving. The endogenous choice of quality makes the effect of skilled labor saving technical progress ambiguous, depending on the additional amount of skilled labor required for quality upgrading as well as the elasticities of demand and supply. Finally, the analysis shows that the relative skill intensity required to produce different varieties within a sector can play a more important role than the relative skill intensity between sectors in determining the impact of both trade and technology on the relative wage.

The model developed in this paper has the potential for a broader application to trade issues that involve both homogeneous and differentiated markets. For example, the model can be used to provide one explanation of “missing trade” as studied in Conway (forthcoming), Davis and Weinstein (2001), and Trefler (1995), that is, the developed countries use more skilled labor to produce higher quality varieties in the differentiated sectors even after accounting for general productivity differences. In Conway and Wu (2001), we will analyze how trade liberalization can cause the South to export varieties which are relatively skilled labor intensive by the South’s standard but unskilled labor intensive by the North’s standard while the opposite is true in the North, which can also affect the overall change in skill content of trade after a tariff reduction.

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## Appendix

### 1. Equilibrium with exogenous quality

#### Closed economy

Since a consumer can choose to buy only good  $Y$  and receive a “reservation” utility of  $I$ , a consumer buys one unit of good  $X$  with quality  $q$  at price  $p_q$  if and only if  $I - p_q + \theta \ln q \geq I$  or  $\mu_x w_l + \lambda_x q^a w_s \leq \theta \ln q$ . Suppose  $\underline{\theta}$  is high and the cost is low ( $a$ ,  $\mu_x$  and  $\lambda_x$  are low), then each consumer buys one unit of good  $X$  under assumption (A-A1). The total consumption and production of good  $X$  is the population size  $L + S$ .

**(A-A1)**  $\mu_x w_l + \lambda_x q^a w_s \leq \underline{\theta} \ln q$  at equilibrium.

Given  $X = L + S$ , the full employment conditions in a closed economy are

$$\mu_x + \mu_y \left(1 + \frac{w_s}{w_l} h_y\right)^{\frac{\sigma}{1-\sigma}} \bar{y} = l, \quad (\text{A.1})$$

$$\lambda_x q^a + h_y \mu_y \left(1 + \frac{w_s}{w_l} h_y\right)^{\frac{\sigma}{1-\sigma}} \bar{y} = s. \quad (\text{A.2})$$

Solving the above full employment conditions yields

$$\bar{y} = \frac{l - \mu_x}{\mu_y} \left(1 + \frac{w_s}{w_l} h_y\right)^{\frac{\sigma}{\sigma-1}}, \quad (\text{A.3})$$

$$h_y = \frac{s - \lambda_x q^a}{l - \mu_x}. \quad (\text{A.4})$$

Substituting equation (4) into (A.3) gives

$$\left(\frac{w_s}{w_l}\right)^\sigma = \frac{l - \mu_x}{s - \lambda_x q^a} \left(\frac{\mu_y}{\lambda_y}\right)^{\sigma-1}. \quad (\text{A.5})$$

Finally, the absolute wages,  $w_l$  and  $w_s$ , are derived from conditions (7) and (A.5), the total production and consumption of good  $Y$ ,  $\bar{y}(L + S)$ , is then calculated from equation (A.3), and the price of good  $X$  is given by  $\mu_x w_l + \lambda_x q^a w_s$ .

#### Small open economy

If the home country is a small open economy, then the price of good  $X$  with exogenous quality  $q$ ,  $p_q^*$ , is determined in the world market. The factor prices are determined by the zero profit conditions (6) and (7) with  $p_q = p_q^*$  and  $p_y = p_y^* = 1$ . Hence, factor prices are determined by world prices and are independent of factor endowments in a small open economy as long as its endowment falls in the imperfect specialization or the FPE parallelogram. The full employment conditions, derived by replacing  $\mu_x$  with  $\mu_x x$  in condition (A.1) and  $\lambda_x q^a$  with  $\lambda_x q^a x$  in condition (A.2), determine the domestic productions of good  $X$  ( $X = x(L+S)$ ) and good  $Y$  ( $Y = \bar{y}(L+S)$ ). Finally the budget constraints give consumptions and the pattern of trade, which depends on the home country's endowments relative to the rest of the world as in a standard H-O model.

Large open economy or integrated economy

If the home country is a large economy trading with the rest of the world or another large economy denoted as the foreign country in this model, then factor prices can once again be equalized across countries because the same zero profit conditions (6) and (7) are satisfied in both countries if their endowments are in the imperfect specialization parallelogram. The only difference is that  $p_q$  is now endogenous.

Since  $w_l^* = w_l$ ,  $w_s^* = w_s$  and  $p_q = p_q^*$ , the factor prices ( $w_l$  and  $w_s$ ), the price of good  $X$  ( $p_q$ ), and productions ( $X$ ,  $X^*$ ,  $Y$  and  $Y^*$ ) are determined jointly by the two zero-profit conditions (6) and (7), one market clearing condition of good  $X$  with a given quality  $q$ ,

$$X + X^* = L + S + L^* + S^*, \quad (\text{A.6})$$

plus two full employment conditions in the home country,

$$\mu_x X + \mu_y \left(1 + \frac{w_s}{w_l} h_y\right)^{\frac{\sigma}{1-\sigma}} Y = L, \quad (\text{A.7})$$

$$\lambda_x q^a X + h_y \mu_y \left(1 + \frac{w_s}{w_l} h_y\right)^{\frac{\sigma}{1-\sigma}} Y = S, \quad (\text{A.8})$$

and two in the foreign country,

$$\mu_x X^* + \mu_y \left(1 + \frac{w_s}{w_l} h_y\right)^{\frac{\sigma}{1-\sigma}} Y^* = L^*, \quad (\text{A.9})$$

$$\lambda_x q^a X^* + h_y \mu_y \left(1 + \frac{w_s}{w_l} h_y\right)^{\frac{\sigma}{1-\sigma}} Y^* = S^*. \quad (\text{A.10})$$

Finally, incomes are calculated from factor prices, consumptions of each variety of good  $X$  are given by the preferences, consumption of good  $Y$  is derived from the budget constraints, and net exports are given by subtracting consumptions from productions.

## 2. Equilibrium with endogenous quality

If firms can choose the qualities of their products, then the equilibrium conditions under autarky or that in a large open economy is the same as those in an integrated economy derived in the main text, except replacing  $\bar{X}(\theta)$  with  $X(\theta) = f(\theta)(L + S)$ ,  $l$  with  $L/(L + S)$  and  $s$  with  $S/(L + S)$  for the home country or  $l$  with  $L^*/(L^* + S^*)$  and  $s$  with  $S^*/(L^* + S^*)$  for the foreign country.

Regardless of the choice of quality, the only difference between a small and a large open economy is the usual price or terms of trade effect reflected by the endogeneity of the relative price(s) of good  $X$ . In a large country, factor prices ( $w_l$  and  $w_s$ ) are no longer determined only by the two zero profit conditions as in a small country, and hence  $w_s/w_l$  has to be solved from the market clearing condition(s) and the full employment conditions jointly. Thus,  $w_s/w_l$  depends on the endowments as well as commodity prices in the world market. This difference stays the same no matter whether quality is endogenous.

If quality is endogenous, the number of varieties of good  $X$  exceeds one. As the number of unknowns exceeds the number of equations, the two full employment conditions are no longer sufficient to determine the production of different varieties of good  $X$  and good  $Y$ . This applies to both a small and a large open economy and thus the pattern of trade in an open economy is indeterminate when firms choose quality endogenously. However, as in the two factors and a continuum of goods model in Dornbusch, Fischer and Samuelson (1980) and Xu (1993), the equilibrium pattern of trade is not crucial in determining the relative wage. The pattern of trade under product differentiation when endowments lie inside or outside the diversification cone can be addressed in a separate paper.

If FPE holds under free trade, then each country produces an arbitrary proportion of different

varieties of the differentiated good if quality is endogenous. While the equilibrium factor prices are the same in all equilibria, the pattern of trade becomes arbitrary when quality becomes a firm's choice variable. Nevertheless, comparing Tables 1 and 2 shows that the difference between a small open economy and a large open economy is largely the same whether or not quality is endogenous. Moreover, if at least one of the countries is a large open economy, then the equilibrium of the integrated economy with endowments  $L + L^*$  and  $S + S^*$  closely resembles that of a closed economy or a large open economy with the same endowments.

Figure 1: Impact of Trade in a Small Open Economy

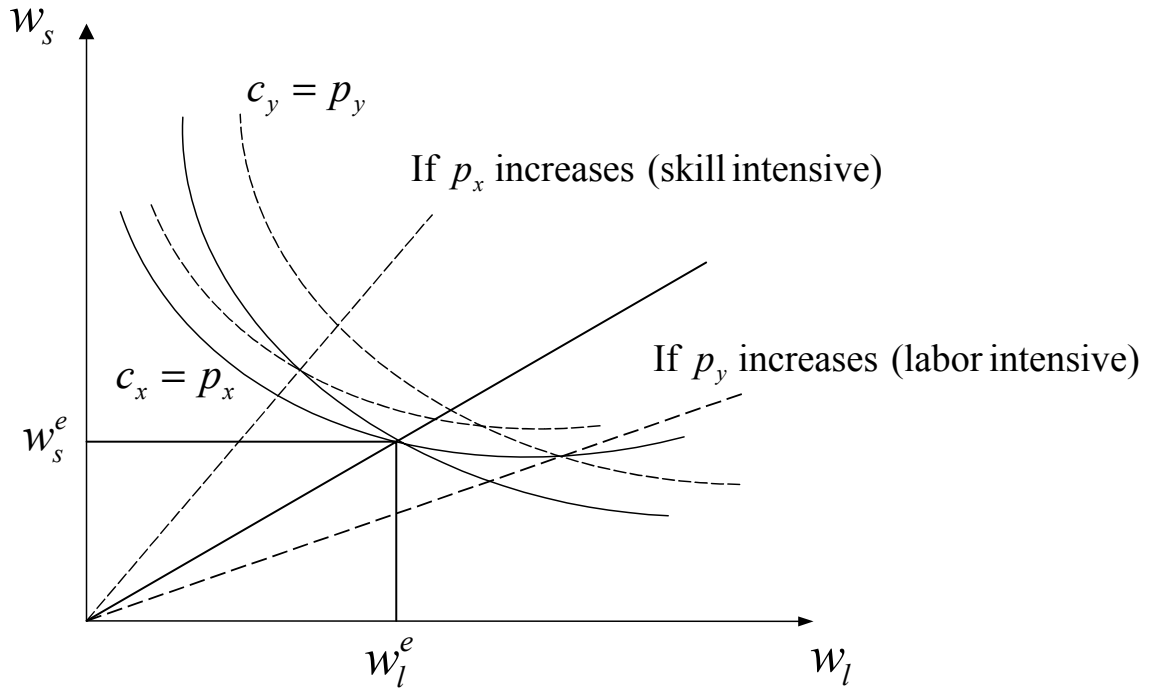


Figure 2: Impact of Technology in a Small Open Economy

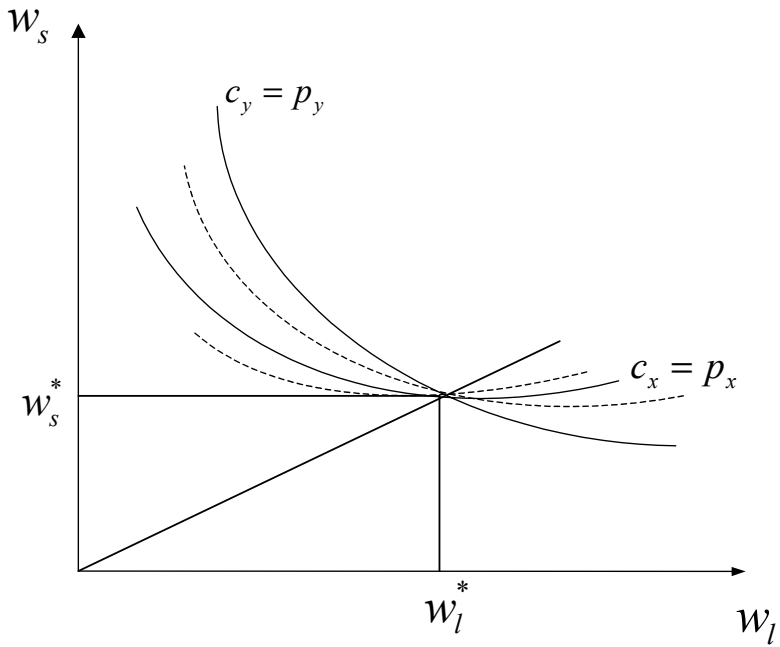
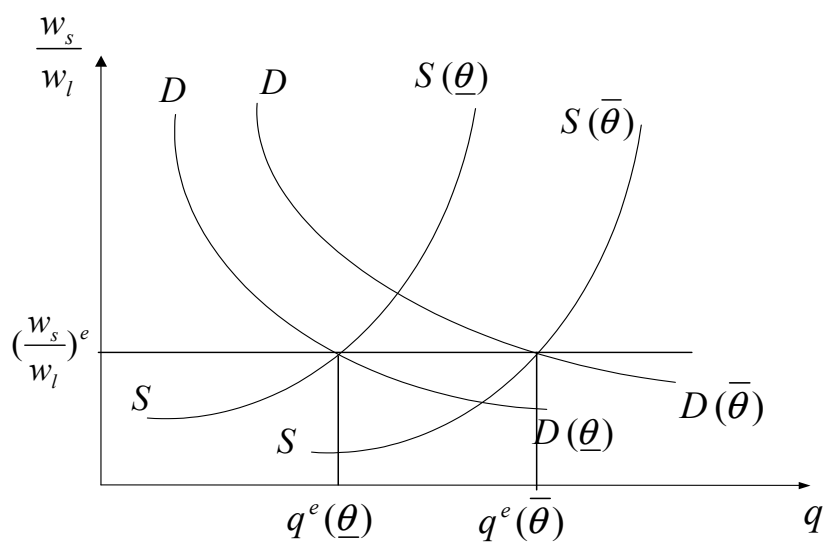


Figure 3: Equilibrium in an Integrated Economy



| Table 1: Equilibrium Conditions under Exogenous Quality |   |   |
|---|---|---|
|   | Small Open Economy  | Large Open Economy  |
| Zero Profit   |   | Closed Economy  |
| X-sector  | $\mu_x w_l + \lambda_x q^a w_s = p_q^*$   | $\mu_x w_l + \lambda_x q^a w_s = p_q$ ( $p_q$ is endogenous)  |
| Y-sector  |   | $\mu_y w_l (1 + \frac{w_s}{w_l} h_y)^{\frac{1}{1-\sigma}} = 1$  |
| Market Clearing   |   | $X + X^* = L + S + L^* + S^*$ $X = L + S$   |
| Full Employment   |   |   |
| Home X-sector   | $\mu_x x d\theta + \mu_y (1 + \frac{w_s}{w_l} h_y)^{\frac{\sigma}{1-\sigma}} \bar{y} = l$             | $\mu_x X + \mu_y (1 + \frac{w_s}{w_l} h_y)^{\frac{\sigma}{1-\sigma}} Y = L$ $\mu_x + \mu_y (1 + \frac{w_s}{w_l} h_y)^{\frac{\sigma}{1-\sigma}} \bar{y} = l$                         |
| Y-sector  | $\lambda_x q^a x d\theta + h_y \mu_y (1 + \frac{w_s}{w_l} h_y)^{\frac{\sigma}{1-\sigma}} \bar{y} = s$ | $\lambda_x q^a X + h_y \mu_y (1 + \frac{w_s}{w_l} h_y)^{\frac{\sigma}{1-\sigma}} Y = S$ $\lambda_x q^a + h_y \mu_y (1 + \frac{w_s}{w_l} h_y)^{\frac{\sigma}{1-\sigma}} \bar{y} = s$ |
| Foreign X-sector  |   | $\mu_x X^* + \mu_y (1 + \frac{w_s}{w_l} h_y)^{\frac{\sigma}{1-\sigma}} Y^* = L^*$   |
| Y-sector  |   | $\lambda_x q^a X^* + h_y \mu_y (1 + \frac{w_s}{w_l} h_y)^{\frac{\sigma}{1-\sigma}} Y^* = S^*$   |

| Table 2: Equilibrium Conditions under Endogenous Quality |   |   |
|--|---|---|
|  | Small Open Economy  | Large Open Economy  |
| Quality  |   | Closed Economy  |
| Zero Profit  |   | $q(\theta) = \sqrt[a]{\frac{\theta}{a \lambda_x w_s}}$  |
| X-sector   | $\mu_x w_l + \frac{\theta}{a} = p_q^* = p^*(\theta)$  | $\mu_x w_l + \frac{\theta}{a} = p_q^* = p^*(\theta)$ ( $p^*(\theta)$ is endogenous)   |
| Y-sector   |   | $\mu_y w_l (1 + \frac{w_s}{w_l} h_y)^{\frac{1}{1-\sigma}} = 1$  |
| Market Clearing  |   | $\bar{X}(\theta) = f(\theta)(L + S + L^* + S^*)$ $X(\theta) = f(\theta)(L + S)$   |
| Full Employment  |   |   |
| X-sector   | $\int_{\underline{\theta}}^{\bar{\theta}} \mu_x x(\theta) d\theta + \mu_y (1 + \frac{w_s}{w_l} h_y)^{\frac{\sigma}{1-\sigma}} \bar{y} = l$                    | $\int_{\underline{\theta}}^{\bar{\theta}} \mu_x \bar{X}(\theta) d\theta + \mu_y (1 + \frac{w_s}{w_l} h_y)^{\frac{\sigma}{1-\sigma}} \bar{Y} = L + L^*$ $\mu_x + \mu_y (1 + \frac{w_s}{w_l} h_y)^{\frac{\sigma}{1-\sigma}} \bar{y} = l$  |
| Y-sector   | $\int_{\underline{\theta}}^{\bar{\theta}} \frac{\theta}{a w_s} x(\theta) d\theta + h_y \mu_y (1 + \frac{w_s}{w_l} h_y)^{\frac{\sigma}{1-\sigma}} \bar{y} = s$ | $\int_{\underline{\theta}}^{\bar{\theta}} \frac{\theta}{a w_s} \bar{X}(\theta) d\theta + h_y \mu_y (1 + \frac{w_s}{w_l} h_y)^{\frac{\sigma}{1-\sigma}} \bar{Y} = S + S^*$ $\int_{\underline{\theta}}^{\bar{\theta}} \frac{\theta}{a w_s} f(\theta) d\theta + h_y \mu_y (1 + \frac{w_s}{w_l} h_y)^{\frac{\sigma}{1-\sigma}} \bar{y} = s$ |